



# Multiplicity dependence of two-particle correlation in $\sqrt{s}=7\text{TeV}$ pp collisions at LHC-ALICE experiment

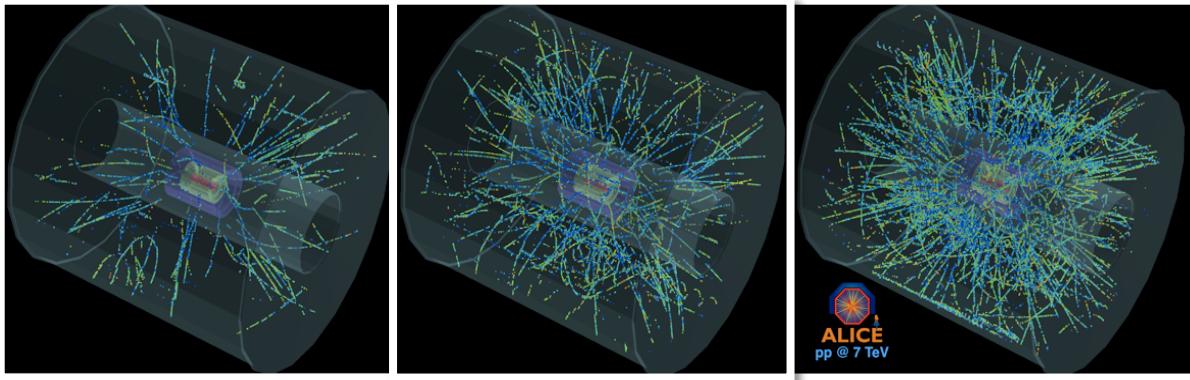


JIHYUN Bhom

8 July 2015

University of Tsukuba

# Outline



- Motivation and High Multiplicity pp Collisions
- Analysis method and result
  - Correlation function
- Conclusion

# Motivation and High Multiplicity Proton-Proton Collision

## -Comparison of CMS and ALICE

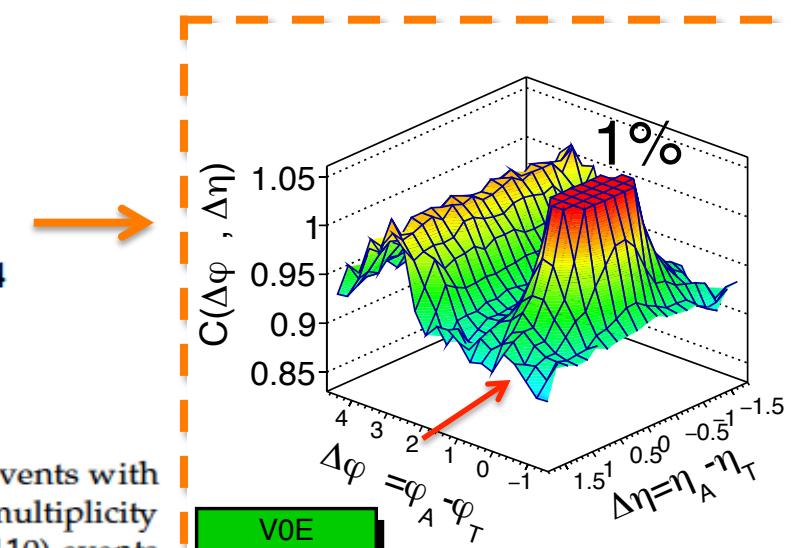
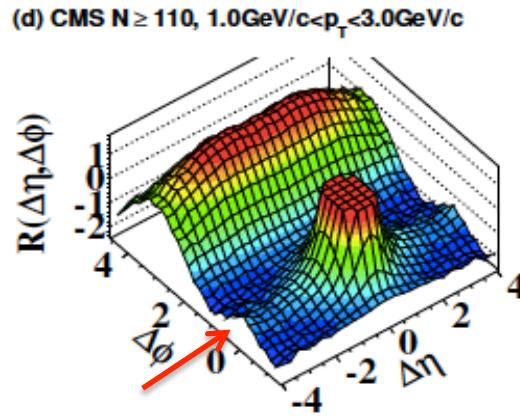
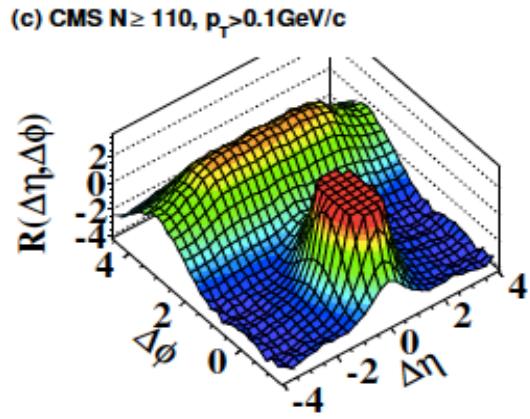
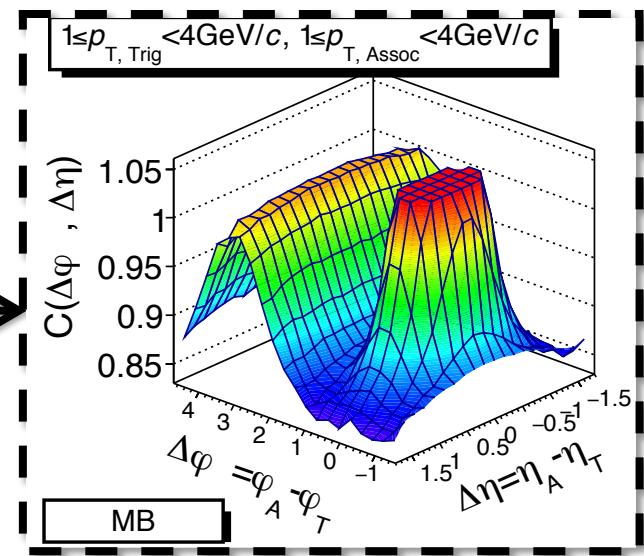
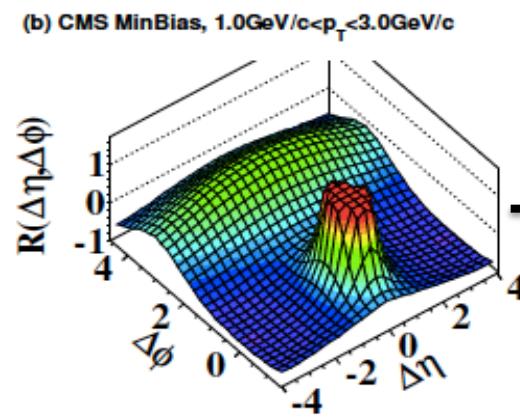
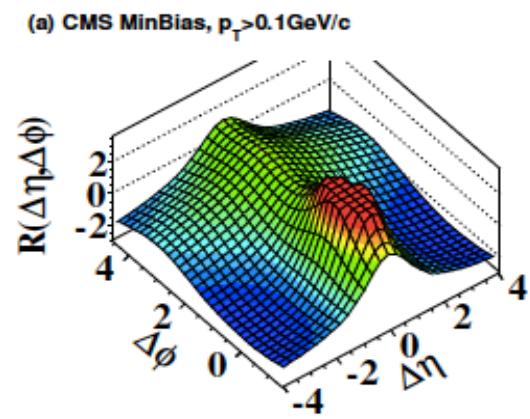
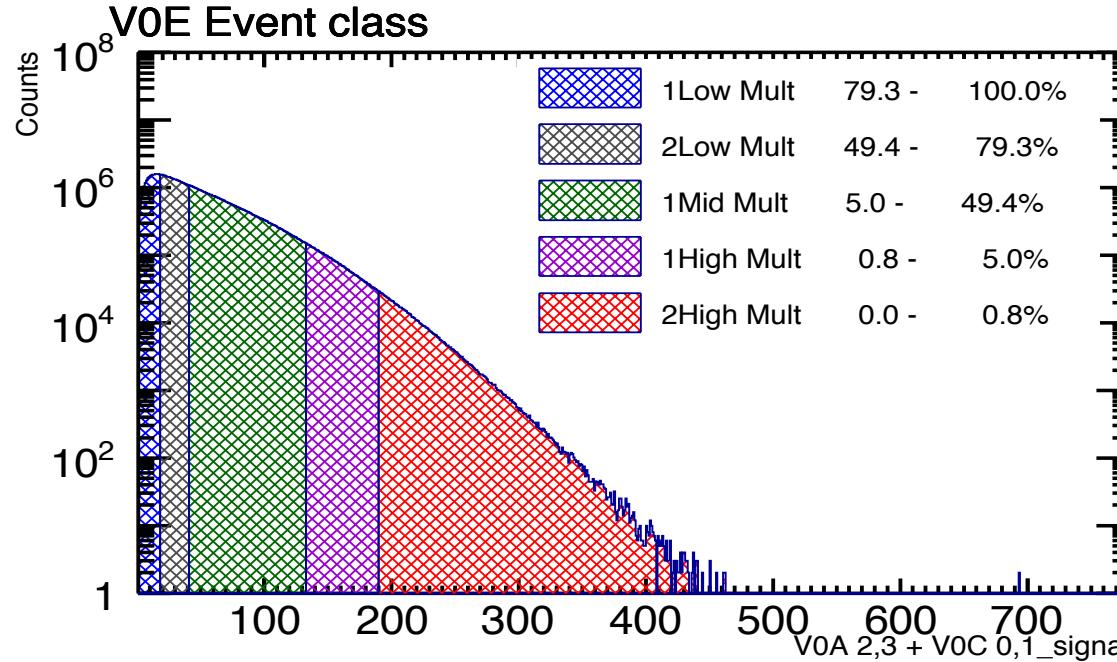


Figure 7: 2-D two-particle correlation functions for 7 TeV  $pp$  (a) minimum bias events with  $p_T > 0.1\text{ GeV}/c$ , (b) minimum bias events with  $1 < p_T < 3\text{ GeV}/c$ , (c) high multiplicity ( $N_{\text{trk}}^{\text{offline}} \geq 110$ ) events with  $p_T > 0.1\text{ GeV}/c$  and (d) high multiplicity ( $N_{\text{trk}}^{\text{offline}} \geq 110$ ) events with  $1 < p_T < 3\text{ GeV}/c$ . The sharp near-side peak from jet correlations is cut off in order to better illustrate the structure outside that region. JHEP 1009:091,2010

# Multiplicity

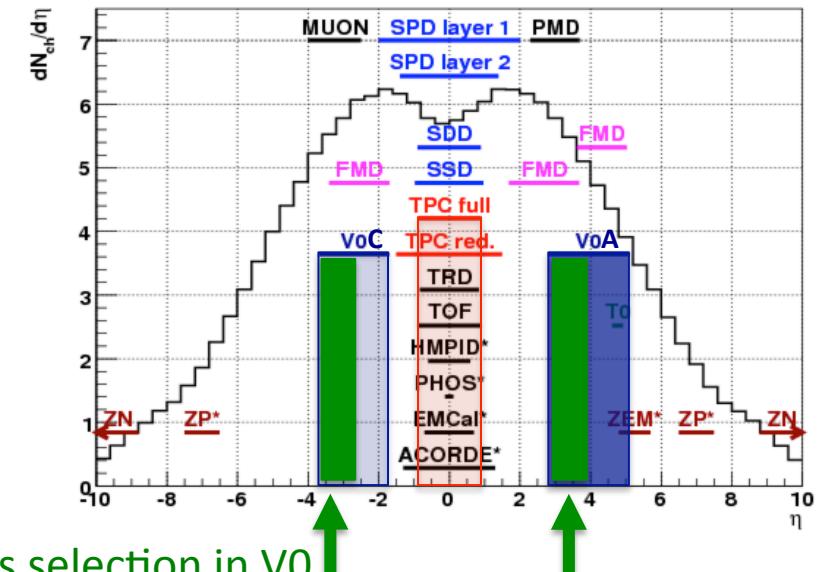
- 5bins (VOE)



Mean number of track

Bit5
2.72
4.30
9.00
16.84
21.68

The acceptance in  $\eta$  of all ALICE subdetectors



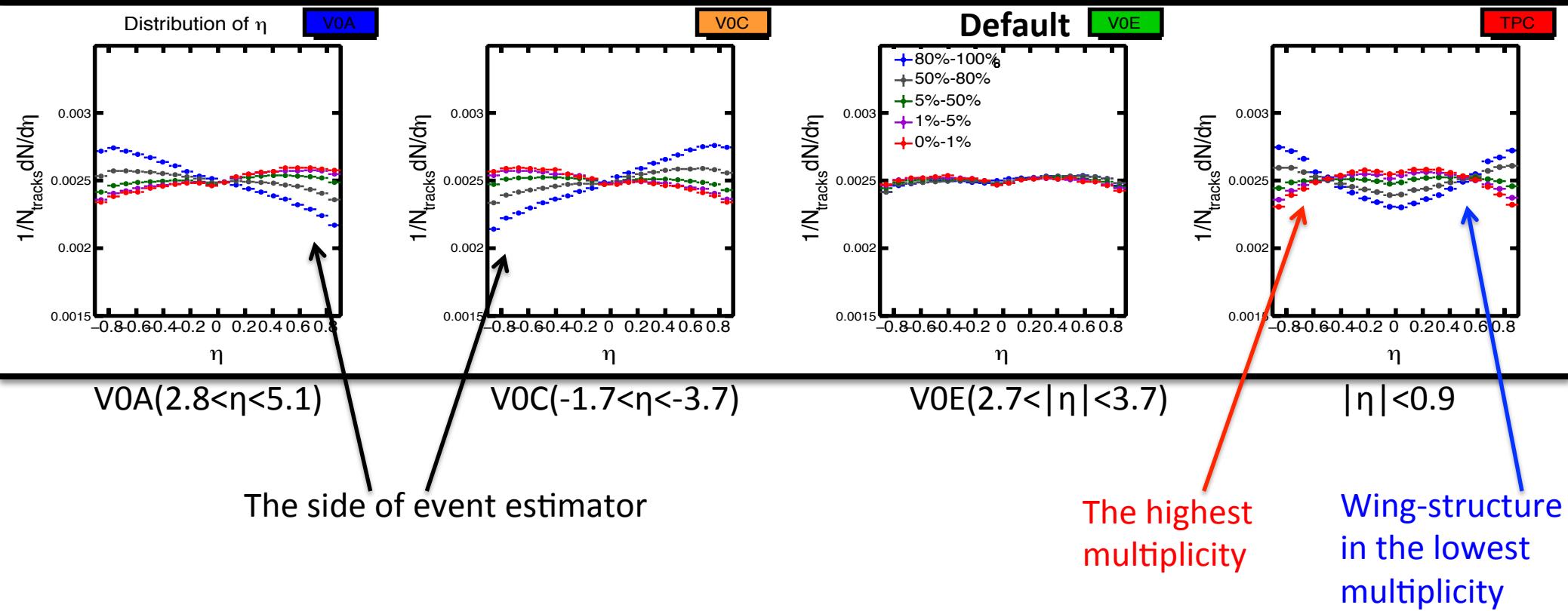
2-rings selection in V0  
to make the trigger acceptance symmetric.

# Distribution of $\eta$

→ Jet veto

→ Jet bias

$1 \leq pT < 4 \text{ GeV}/c$

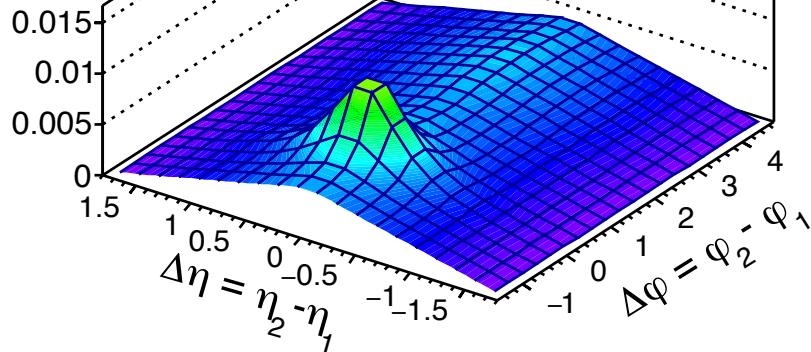


→ The symmetric V0 acceptance for event multiplicity(event activity or centrality) definition is important to reduce the asymmetry in  $\eta$  distribution.

# Definition of two-particle correlation

Same pair

$$S(\Delta\varphi, \Delta\eta) = \frac{1}{N_{\text{same}}} \frac{d^2 N_{\text{same}}}{d\Delta\varphi d\Delta\eta}$$



$1 \leq p_{T, \text{Trig}} < 4 \text{ GeV}/c$

$1 \leq p_{T, \text{Assoc}} < 4 \text{ GeV}/c$

Minimum Bias

MB

mixing Background

$$B(\Delta\varphi, \Delta\eta) = \frac{1}{N_{\text{mix}}} \frac{d^2 N_{\text{mix}}}{d\Delta\varphi d\Delta\eta}$$

0.006

0.004

0.002

0

0.002

0.004

0.006

0.008

0.01

0.015

0.02

0.025

0.03

0.035

0.04

0.045

0.05

0.055

0.06

0.065

0.07

Correlation

$$C(\Delta\varphi, \Delta\eta) = \frac{S(\Delta\varphi, \Delta\eta)}{B(\Delta\varphi, \Delta\eta)}$$

1

1

1

1

1

1

1

1

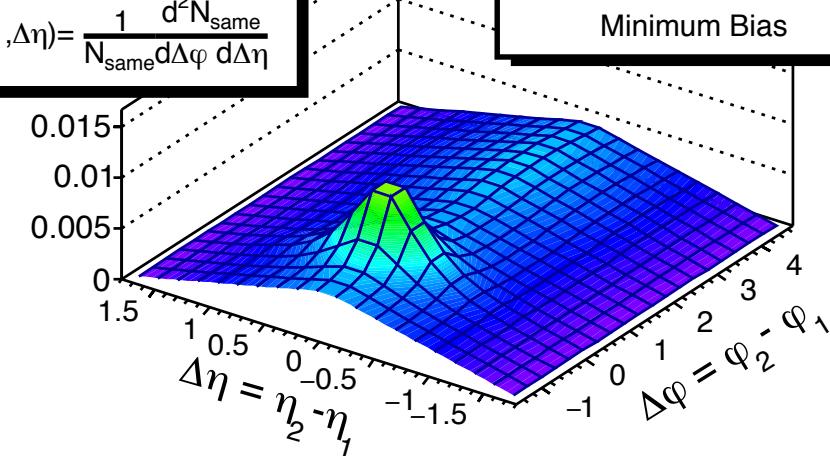
1

1

1

1

1



Associ. Yield per Trig.

$$\text{Yield}(\Delta\varphi, \Delta\eta) = \frac{N_{\text{same}}}{N_{\text{Trig}}} C(\Delta\varphi, \Delta\eta) \frac{1}{\text{efficiency}}$$

4

6

8

10

12

14

16

18

20

22

24

26

28

30

32

34

36

38

40

42

44

46

48

50

52

54

56

58

60

62

64

66

68

70

72

74

76

78

80

82

84

86

88

90

92

94

96

98

100

102

104

106

108

110

112

114

116

118

120

122

124

126

128

130

132

134

136

138

140

142

144

146

148

150

152

154

156

158

160

162

164

166

168

170

172

174

176

178

180

182

184

186

188

190

192

194

196

198

200

202

204

206

208

210

212

214

216

218

220

222

224

226

228

230

232

234

236

238

240

242

244  
246  
248  
250  
252  
254  
256  
258  
260  
262  
264  
266  
268  
270  
272  
274  
276  
278  
280  
282  
284  
286  
288  
290  
292  
294  
296  
298  
300  
302  
304  
306  
308  
310  
312  
314  
316  
318  
320  
322  
324  
326  
328  
330  
332  
334  
336  
338  
340  
342  
344  
346  
348  
350  
352  
354  
356  
358  
360  
362  
364  
366  
368  
370  
372  
374  
376  
378  
380  
382  
384  
386  
388  
390  
392  
394  
396  
398  
400  
402  
404  
406  
408  
410  
412  
414  
416  
418  
420  
422  
424  
426  
428  
430  
432  
434  
436  
438  
440  
442  
444  
446  
448  
450  
452  
454  
456  
458  
460  
462  
464  
466  
468  
470  
472  
474  
476  
478  
480  
482  
484  
486  
488  
490  
492  
494  
496  
498  
500  
502  
504  
506  
508  
510  
512  
514  
516  
518  
520  
522  
524  
526  
528  
530  
532  
534  
536  
538  
540  
542  
544  
546  
548  
550  
552  
554  
556  
558  
560  
562  
564  
566  
568  
570  
572  
574  
576  
578  
580  
582  
584  
586  
588  
590  
592  
594  
596  
598  
600  
602  
604  
606  
608  
610  
612  
614  
616  
618  
620  
622  
624  
626  
628  
630  
632  
634  
636  
638  
640  
642  
644  
646  
648  
650  
652  
654  
656  
658  
660  
662  
664  
666  
668  
670  
672  
674  
676  
678  
680  
682  
684  
686  
688  
690  
692  
694  
696  
698  
700  
702  
704  
706  
708  
710  
712  
714  
716  
718  
720  
722  
724  
726  
728  
730  
732  
734  
736  
738  
740  
742  
744  
746  
748  
750  
752  
754  
756  
758  
760  
762  
764  
766  
768  
770  
772  
774  
776  
778  
780  
782  
784  
786  
788  
790  
792  
794  
796  
798  
800  
802  
804  
806  
808  
810  
812  
814  
816  
818  
820  
822  
824  
826  
828  
830  
832  
834  
836  
838  
840  
842  
844  
846  
848  
850  
852  
854  
856  
858  
860  
862  
864  
866  
868  
870  
872  
874  
876  
878  
880  
882  
884  
886  
888  
890  
892  
894  
896  
898  
900  
902  
904  
906  
908  
910  
912  
914  
916  
918  
920  
922  
924  
926  
928  
930  
932  
934  
936  
938  
940  
942  
944  
946  
948  
950  
952  
954  
956  
958  
960  
962  
964  
966  
968  
970  
972  
974  
976  
978  
980  
982  
984  
986  
988  
990  
992  
994  
996  
998  
1000

1000

1002

1004

1006

1008

1010

1012

1014

1016

1018

1020

1022

1024

1026

1028

1030

1032

1034

1036

1038

1040

1042

1044

1046

1048

1050

1052

1054

1056

1058

1060

1062

1064

1066

1068

1070

1072

1074

1076

1078

1080

1082

1084

1086

1088

1090

1092

1094

1096

1098

1100

1102

1104

1106

1108

1110

1112

1114

1116

1118

1120

1122

1124

1126

1128

1130

1132

1134

1136

1138

1140

1142

1144

1146

1148

1150

1152

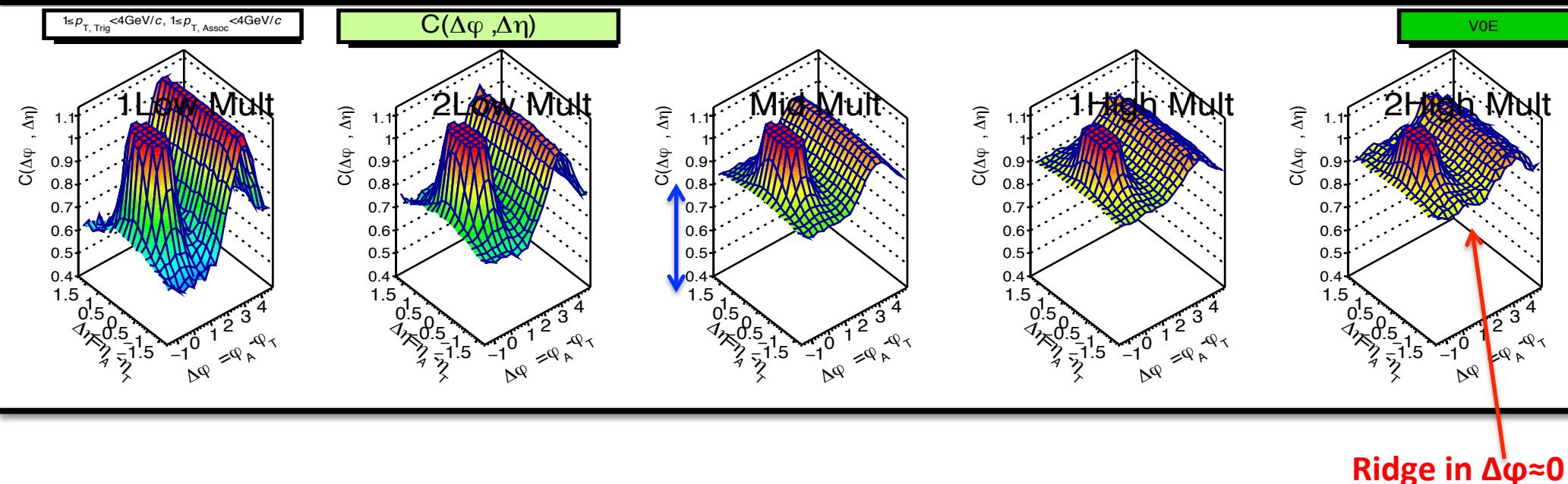
1154

1156

1158</p

# Correlation function with multiplicity dependence

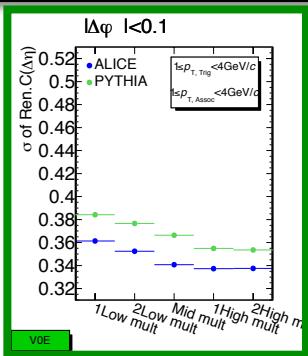
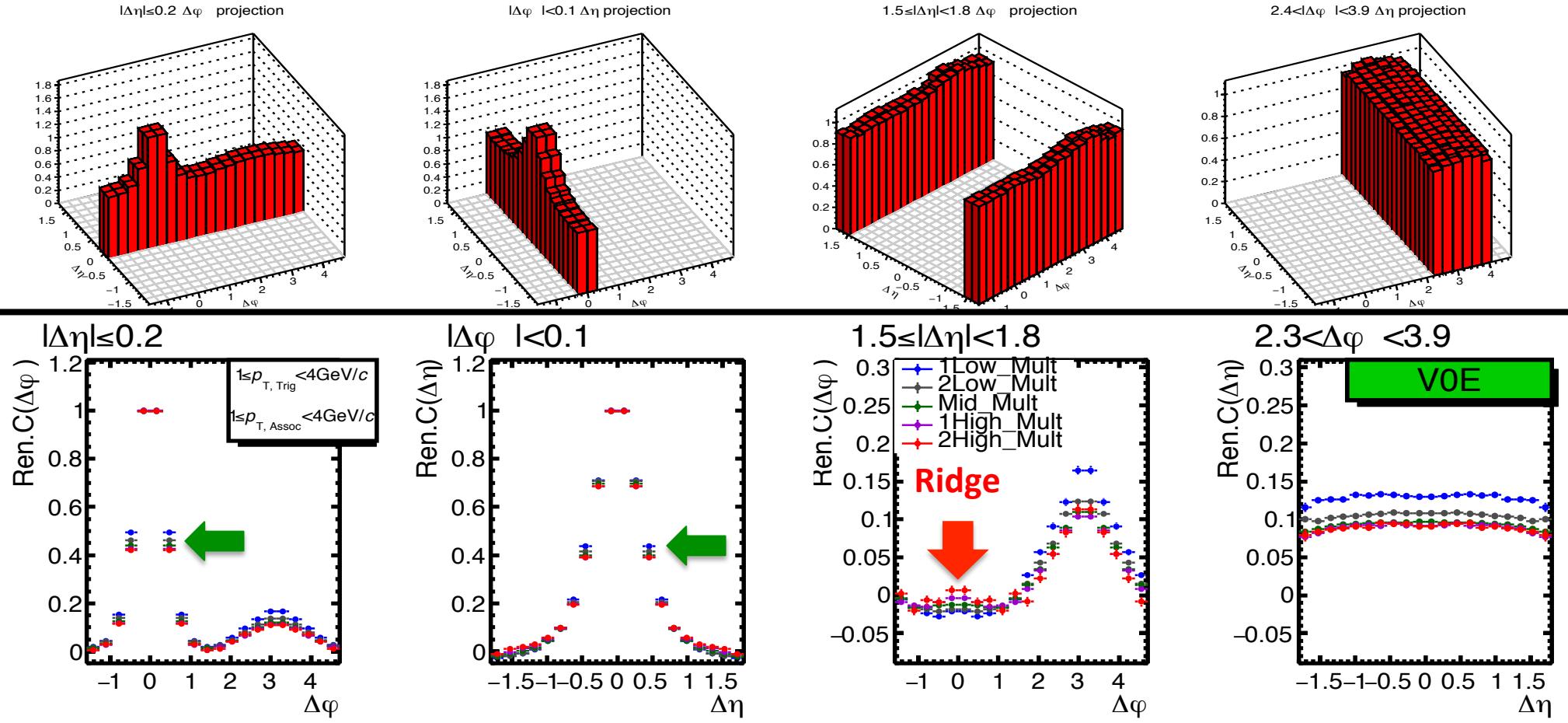
$1 \leq p_{T,\text{Trig}} < 4 \text{ GeV}/c$   
 $1 \leq p_{T,\text{Assoc}} < 4 \text{ GeV}/c$



Due to the combinatorial mixing back ground (**C=S/M**),

- uncorrelated parts increase with higher multiplicity.
  - Near side jets in  $(\Delta\varphi, \Delta\eta) \approx (0, 0)$  reduce with higher multiplicity.
  - Away side jets in  $\Delta\varphi \approx \pi$  are almost constant with multiplicity dependence.
  - The **ridge structure in  $\Delta\varphi \approx 0$**  in the highest multiplicity.
- The shape study.

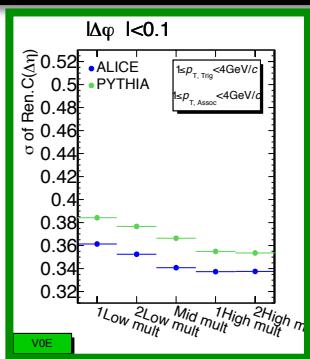
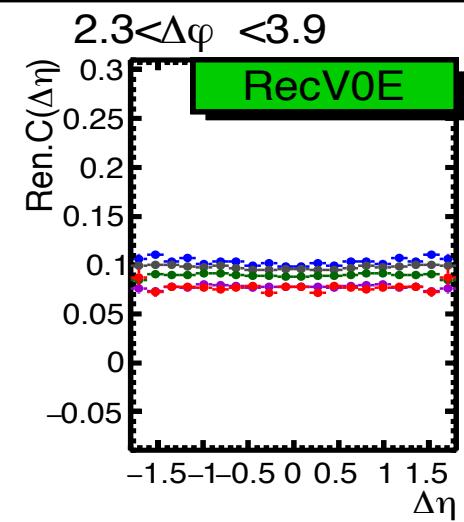
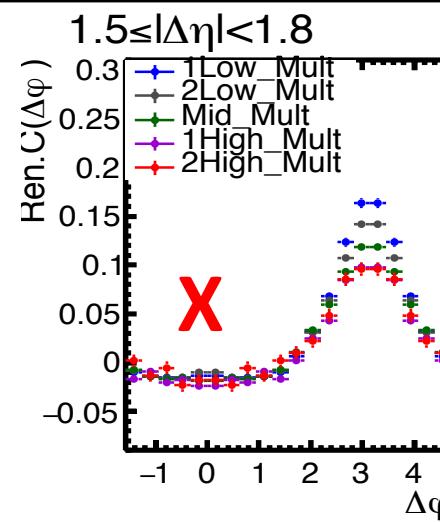
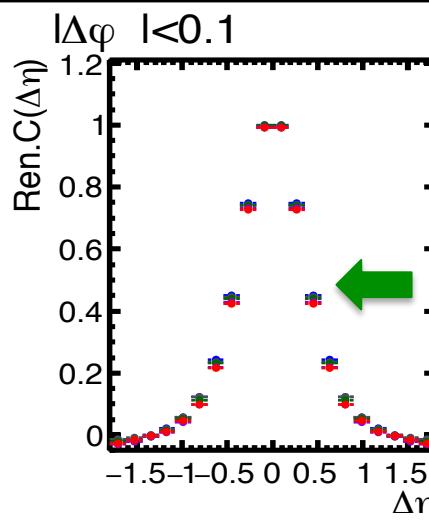
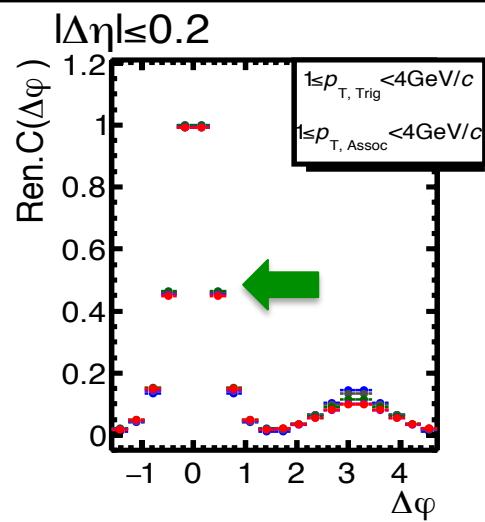
# Projection of $\Delta\varphi$ and $\Delta\eta$ of Renormalized Correlation functions



1. **Ridge** in  $\Delta\varphi \approx 0$  in the highest and 2<sup>nd</sup> highest multiplicities.
2. Near side jets size are narrower with increasing multiplicities.
3. The shapes continuously change with multiplicity.

# Projection of $\Delta\varphi$ and $\Delta\eta$ of Renormalized Correlation functions

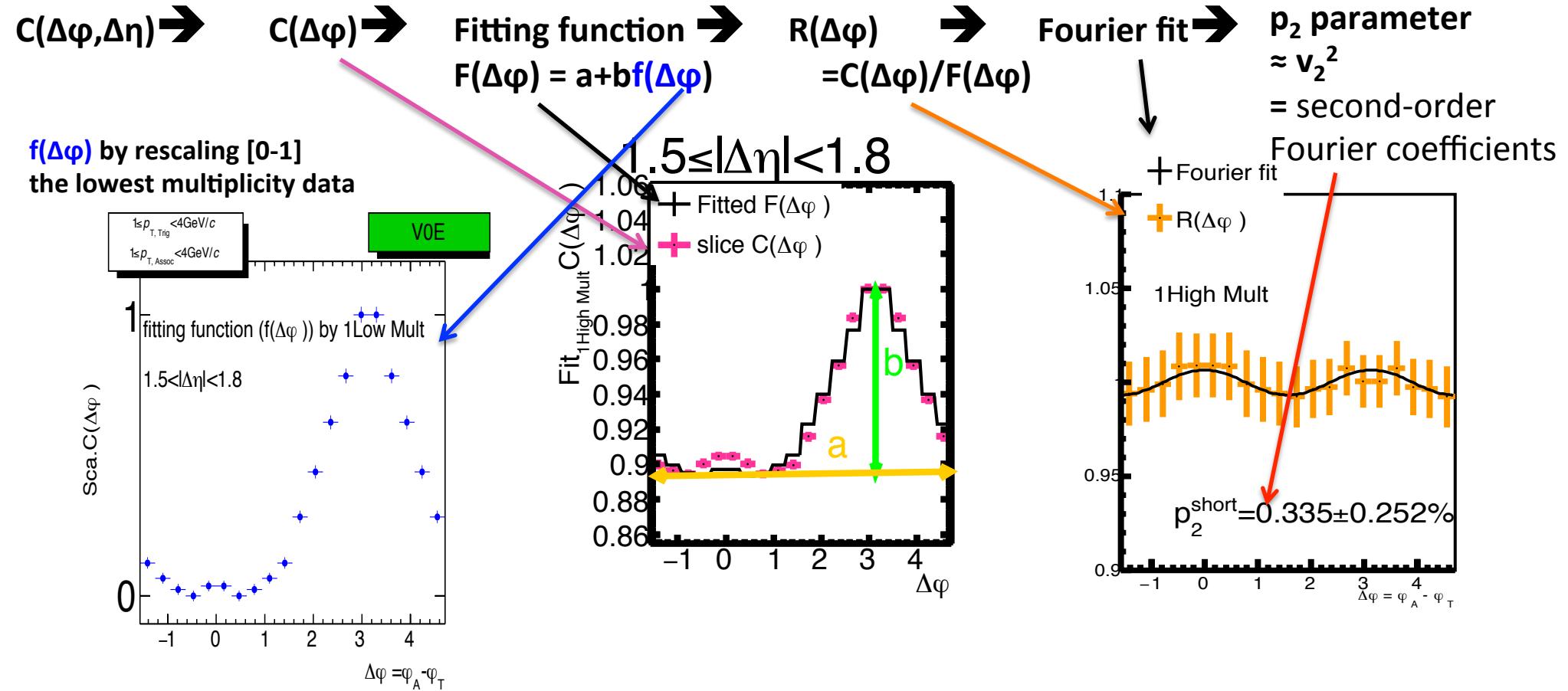
PYTHIA



Near side jets size are narrower with increasing multiplicities.

# Strategy for $p_2$ parameter

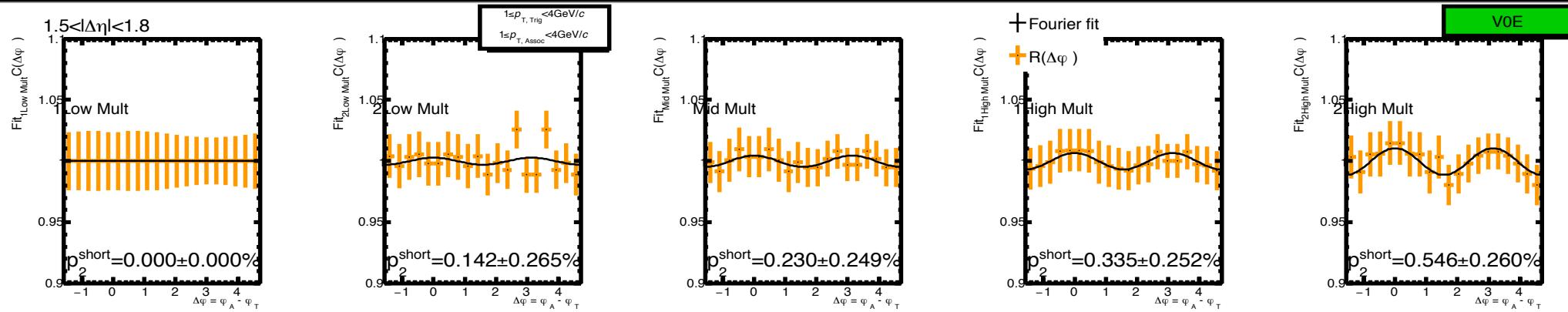
## - Reference fitting



# The ratio of $C(\Delta\varphi)$ to $F(\Delta\varphi)$

$1 \leq p_T_{\text{Trig}} < 4 \text{ GeV}/c$   
 $1 \leq p_T_{\text{Assoc}} < 4 \text{ GeV}/c$

TPC-TPC correlation,  $1.5 \leq |\Delta\eta| < 1.8$



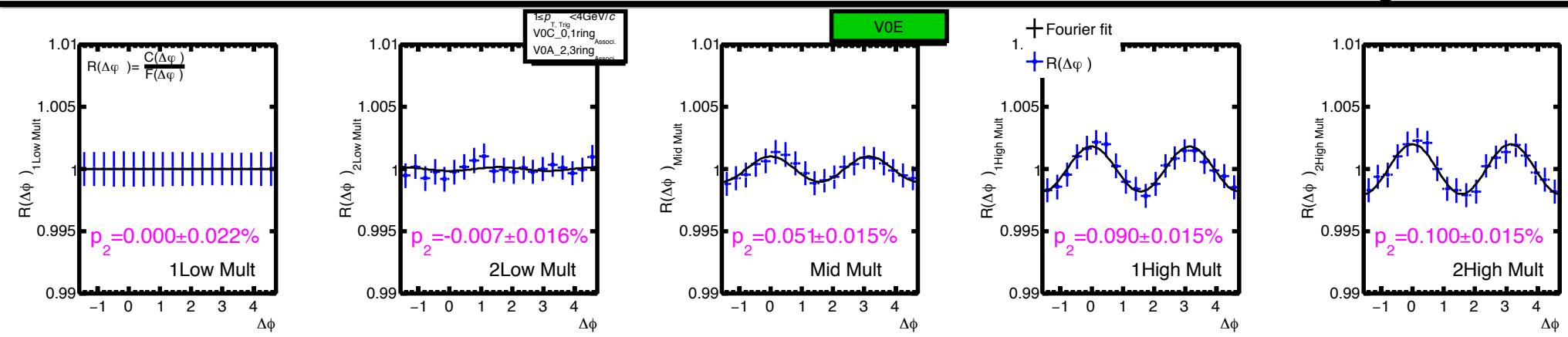
-  $p_2$  parameter is the amplitude of the 2nd order oscillation

→ Elliptic shape

# The ratio of $C(\Delta\varphi)$ to $F(\Delta\varphi)$

TPC-V0 correlation,  $1.8 < |\Delta\eta| < 4.8$

$1 \leq pT_{\text{Trig}} < 4 \text{ GeV}/c$   
 VOC 0, 1 Ring  
 VOA 2, 3 Ring



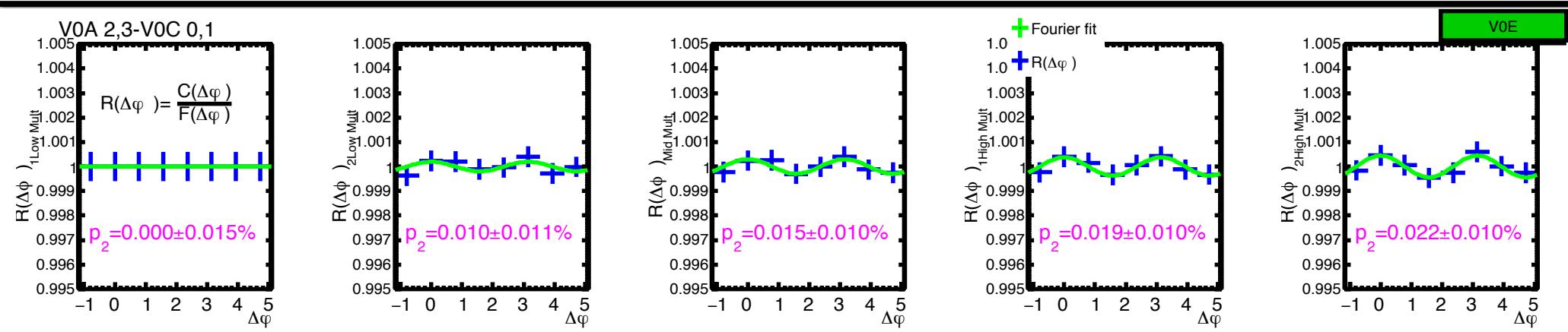
-  $p_2$  parameter is the amplitude of the 2nd order oscillation

→ Elliptic shape shown up to  $|\Delta\eta| \sim 4.8$ .

# The ratio of $C(\Delta\varphi)$ to $F(\Delta\varphi)$

V0-V0 correlation,  $5.5 < |\Delta\eta| < 7.6$

VOC 0, 1 Ring  
VOA 2, 3 Ring



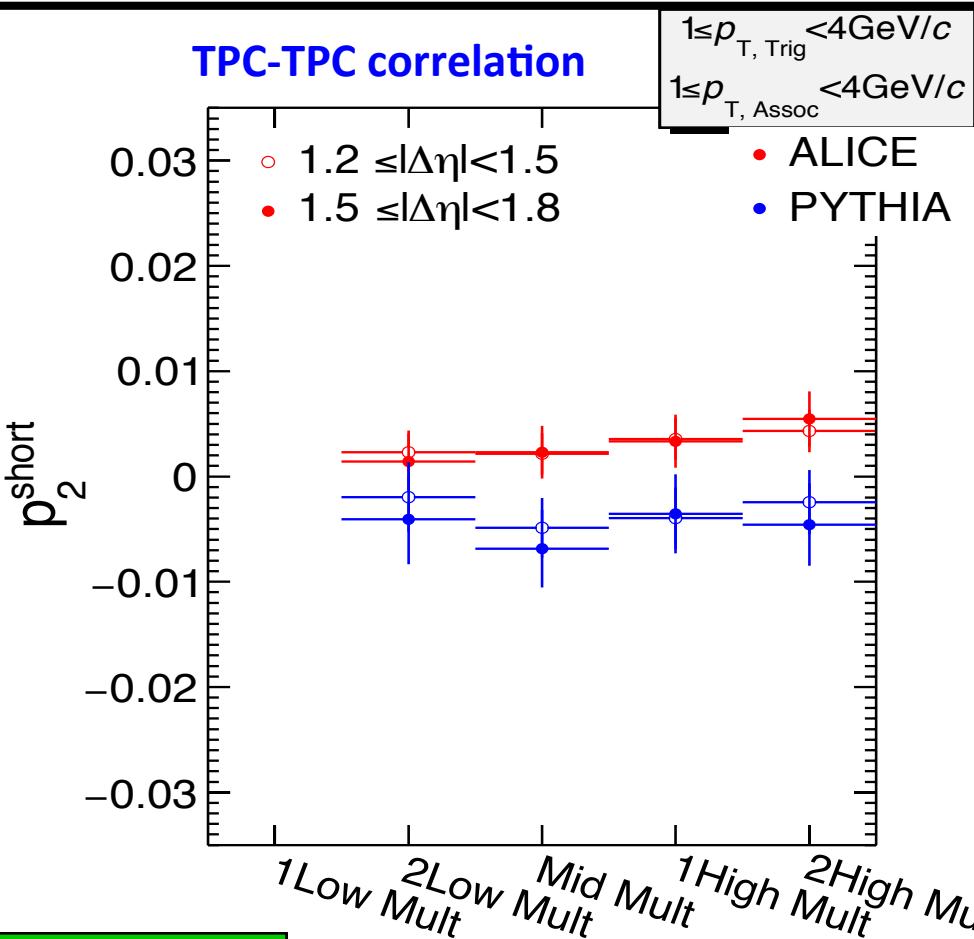
-  $p_2$  parameter is the amplitude of the 2nd order oscillation

→ Elliptic shape shown up to  $|\Delta\eta| \sim 7.6$ .

# Summary 1.1

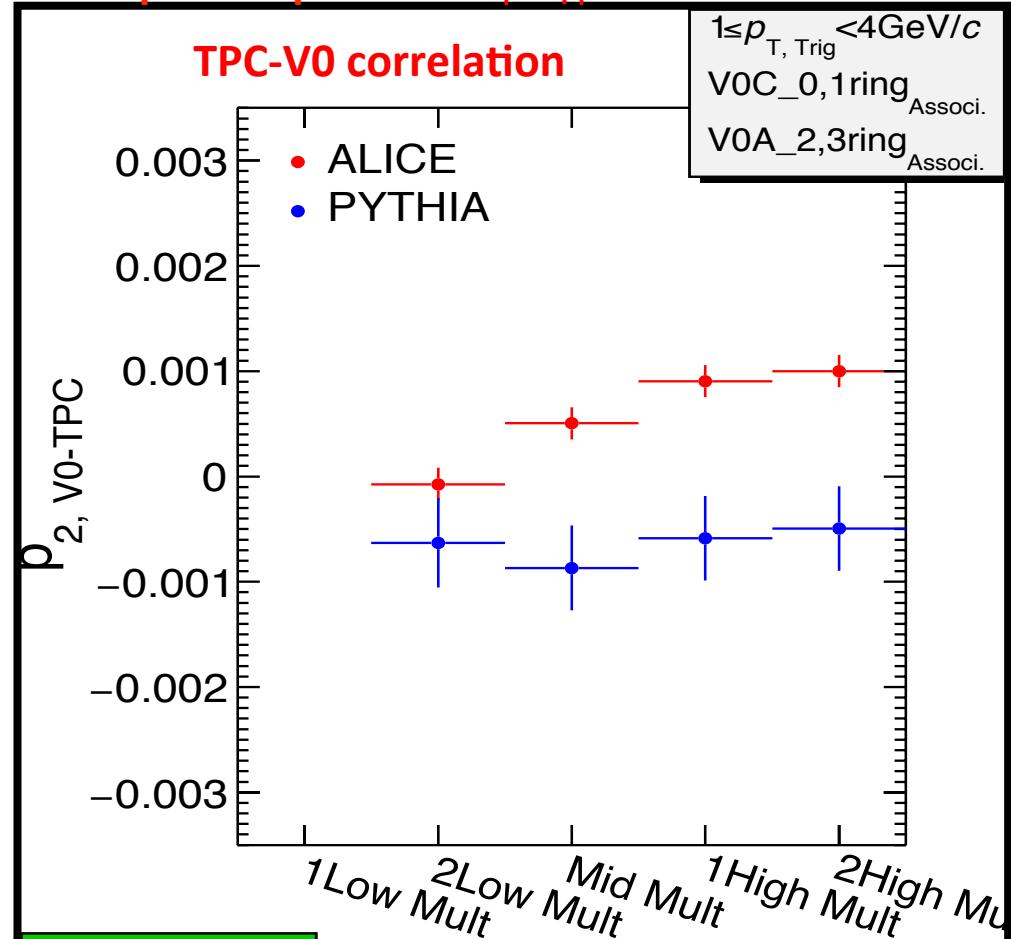
## The shape study of $C(\Delta\varphi)$

TPC-TPC correlation



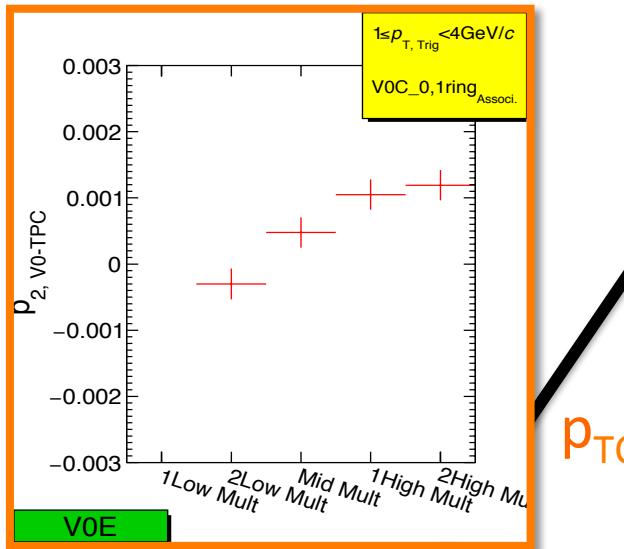
→ Elliptic shape in  $1.8 < |\Delta\eta| < 4.8$

TPC-V0 correlation



# 3-sub event method

## -The $p_2^{\text{long}}$ extraction



$1.8 < |\Delta\eta| < 4.6$

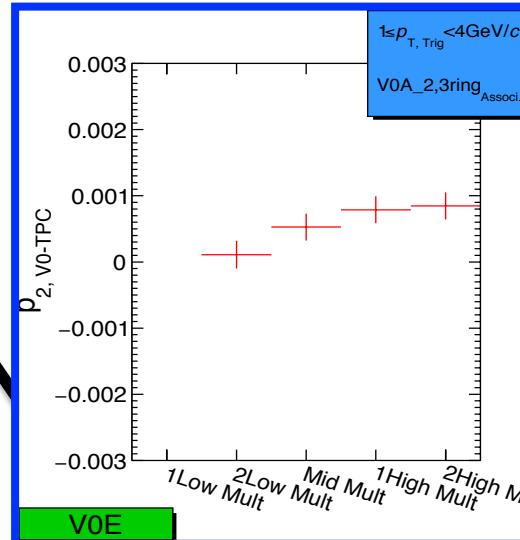
V0C, C

TPC, T

$p_{TC}$

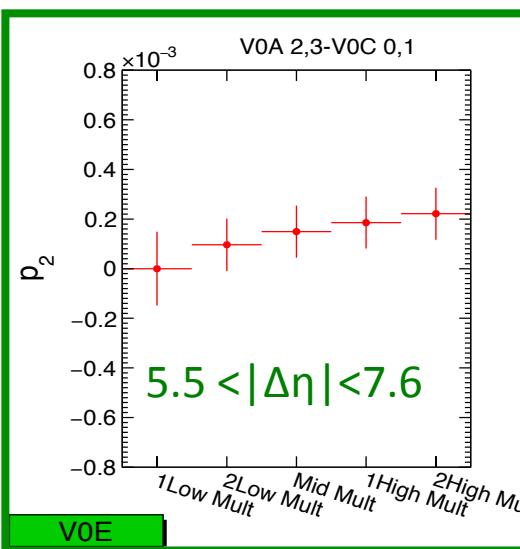
$p_{TA}$

$p_{AC}$



$1.9 < |\Delta\eta| < 4.8$

V0A, A



$5.5 < |\Delta\eta| < 7.6$

$$p_{TT} = v_2^{\text{TPC}} v_2^{\text{TPC}} \\ = p_2^{\text{short}}$$

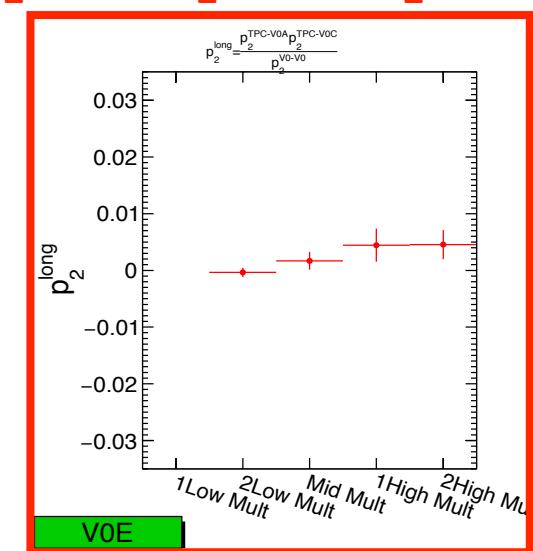
$$p_{TC} = v_2^{\text{TPC}} v_2^{\text{V0C}}$$

$$p_{TA} = v_2^{\text{TPC}} v_2^{\text{V0A}}$$

$$p_{AC} = v_2^{\text{V0A}} v_2^{\text{V0C}}$$

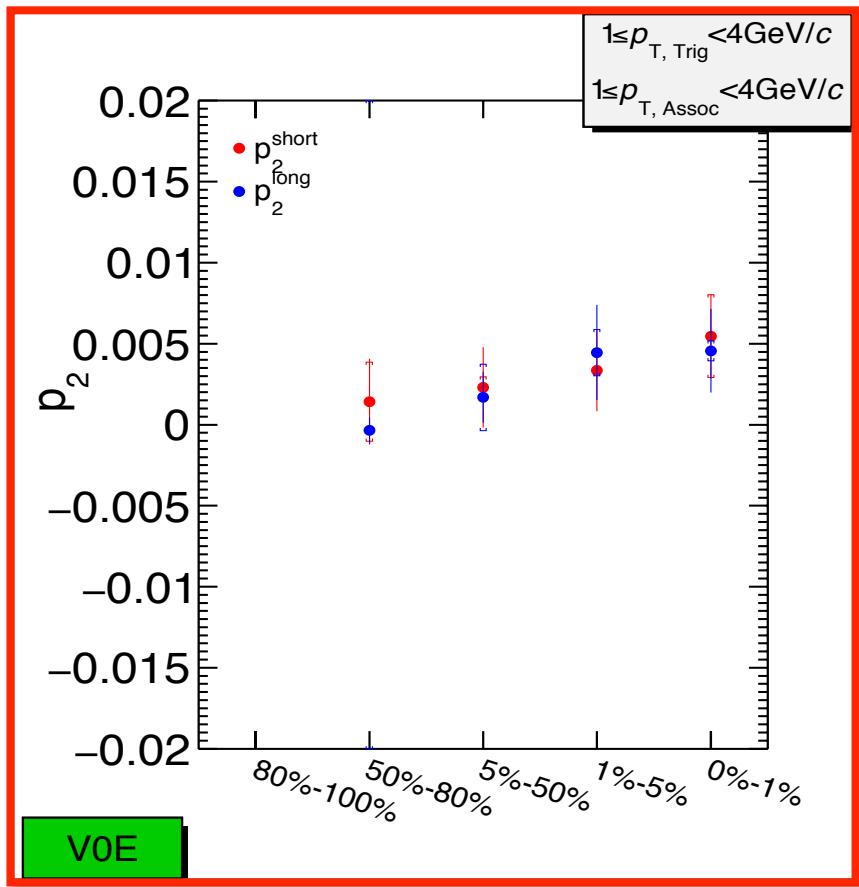
$$P_2^{\text{long}} = p_{TC} \times p_{TA} / p_{AC}$$

$$p_2^{\text{long}} \approx p_2^{\text{short}} \approx (v_2^{\text{TPC}})^2$$



## Summary 1.2

### The extraction of $p_2^{\text{short}}$ and $p_2^{\text{long}}$



1.1.  $v_2 \sim 7.4 \pm 1.8 \%$   
 $\sim \sqrt{p_2}$

1.2. Consistent  $v_2$  measurements (relative  $v_2$  evolution in  $p_2$  parameter) with very different rapidity gap cuts.

$$\rightarrow p_2^{\text{short}} \approx p_2^{\text{long}}$$

# Possible explanation of ridge

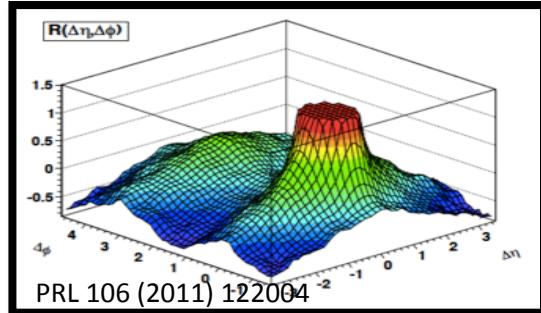
## 1. Hydrodynamic flow O

PRL 106 (2011) 122004

-> Due to fixed trigger particle in analysis method,  
the position of ridge is located in  $\Delta\varphi \approx 0$ .

->EPOS may describe ridge in pp collisions in intermediate pT.  
But the 2-D shape is still different with experimental result.

→the position of ridge free from jet in  $\Delta\varphi$ .



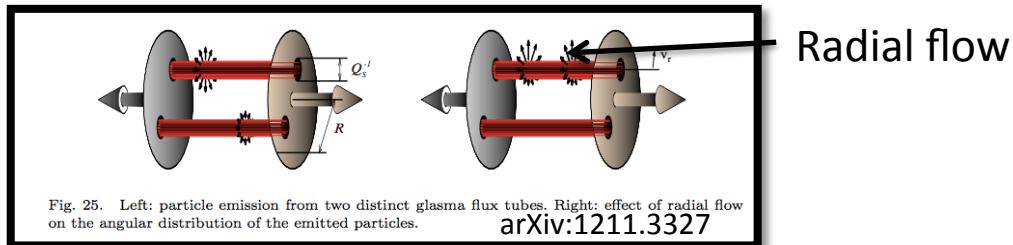
## 2. Color Glasma Condensate (CGC) O

Phys.Lett.B697,21(2011)

arXiv:1211.3327

-> We do not know.

→the position of ridge free from jet in  $\Delta\varphi$ .



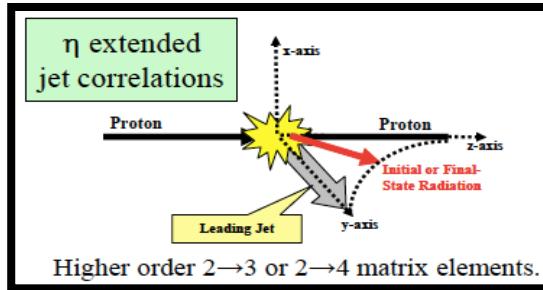
## 3. Jet-induced ridge X

PRC 84,024901,2011

PRC 83,024911,2011

->the ridge should depend on high pT.

→the position of ridge depend on jet in  $\Delta\varphi$ .

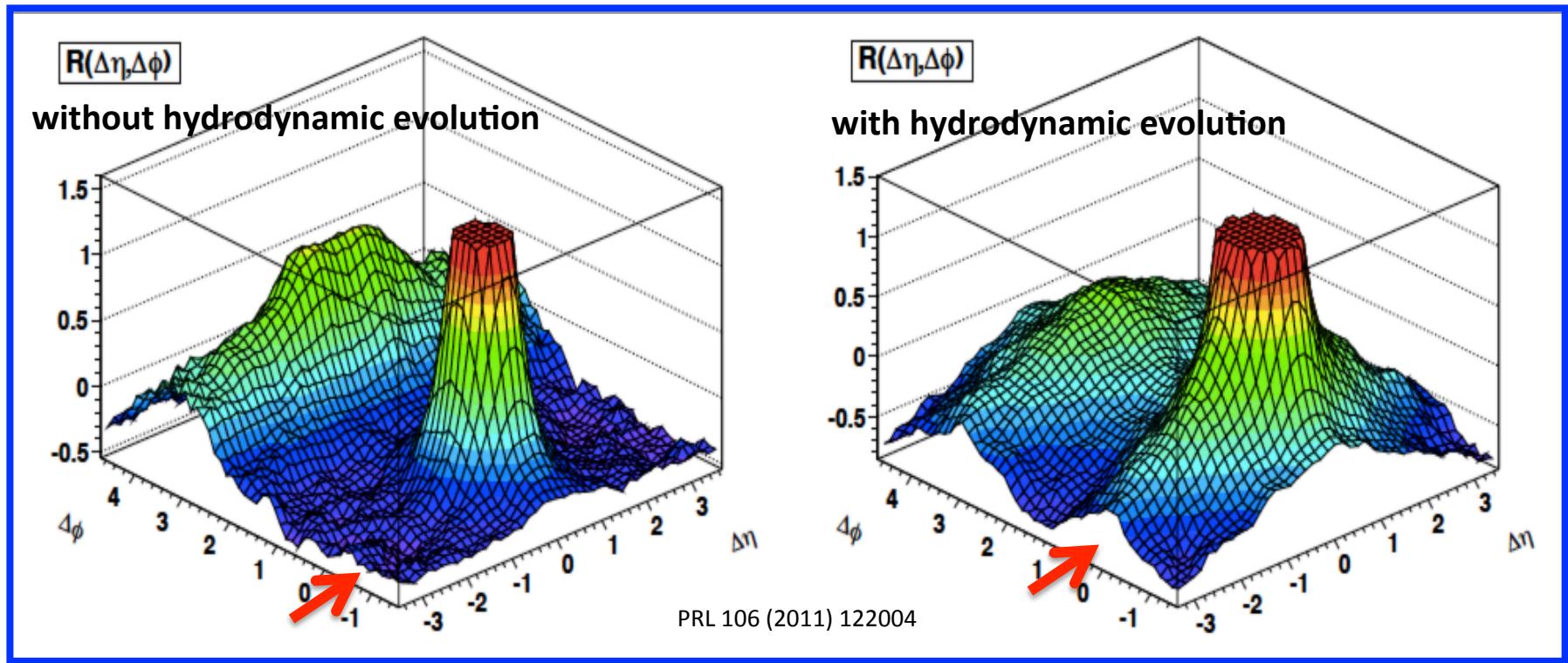


## 4. MPI (Multi Parton Interaction) X

-> arXiv:1203.2048v2

17 -> very weak or no dependence of multiplicity

2-D dihadron correlation functions from the EPOS model  
 for high multiplicity events in pp collisions at  $\sqrt{s} = 7$  TeV,  $1 < p_T < 3$  GeV

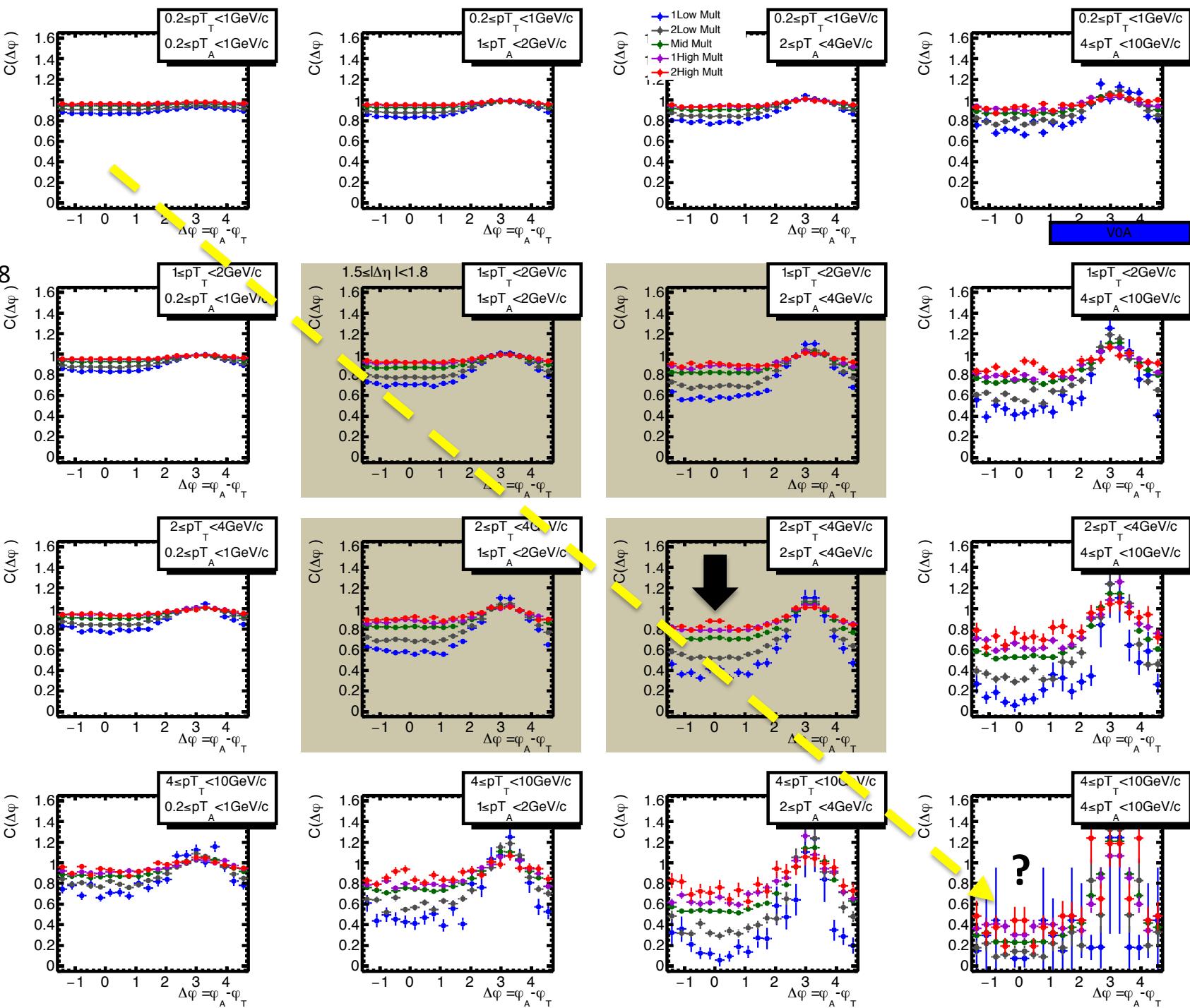


cut off the near side peak

→ Hydrodynamics model predicts a **ridge structure in  $\Delta\phi \approx 0$**  in pp collisions in intermediate  $p_T$ .

# Dependence of $p_T$

-  $C(\Delta\varphi)$  in  $1.5 \leq |\Delta\eta| < 1.8$



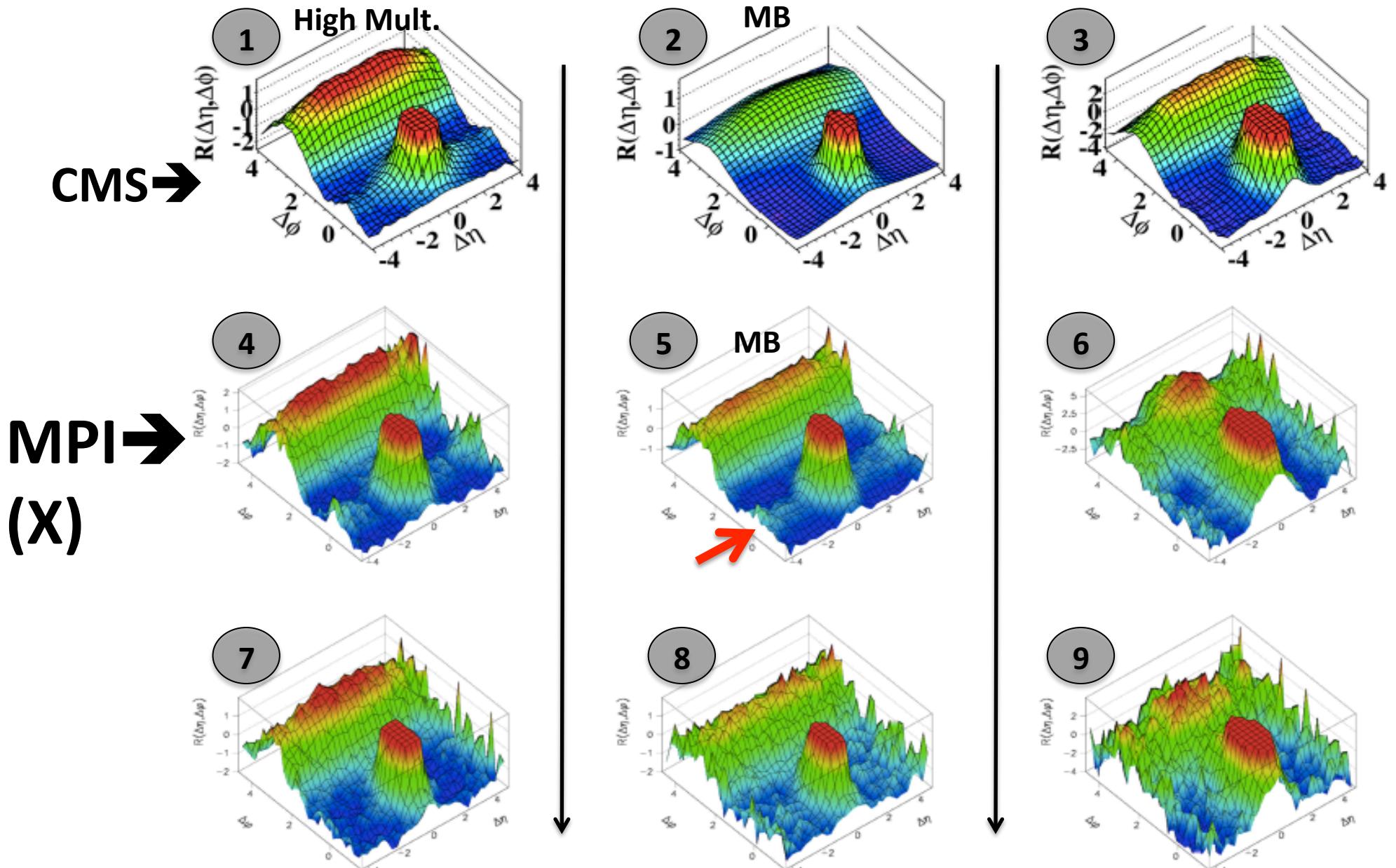


Figure 7: Results for  $R(\Delta\eta, \Delta\phi)$ : original (top row), Z2R (middle row) and Z2R' (bottom row); (left) high multiplicity, moderate  $p_T$ ; (centre) minimum bias, moderate  $p_T$ ; (right) high multiplicity, all  $p_T > 0.1$  GeV. arXiv:1203.2048v2

# Conclusion

- Multiplicity dependence of pp collisions
  - Two-particle correlation function  $C(\Delta\varphi)$  in  **$\sqrt{s}=7\text{TeV}$  pp collisions** at LHC-ALICE.
- Correlation function
  - Observation of **Ridge at  $\Delta\varphi \approx 0$**  in pp collisions for high multiplicity.
  - The correlation functions **continuously** change with multiplicity.
  - Jet shapes are different with multiplicity.
  - **elliptic parameter**  $p_2^{\text{short}}$  and  $p_2^{\text{long}}$ .
  - **$v_2 \sim 7.4\%$**
- MC(PYTHIA) cannot explain the experimental result.
  - **Hydrodynamics** (EPOS) may describe ridge in pp collisions in intermediate pT.

# Back up

# Pythia event generator

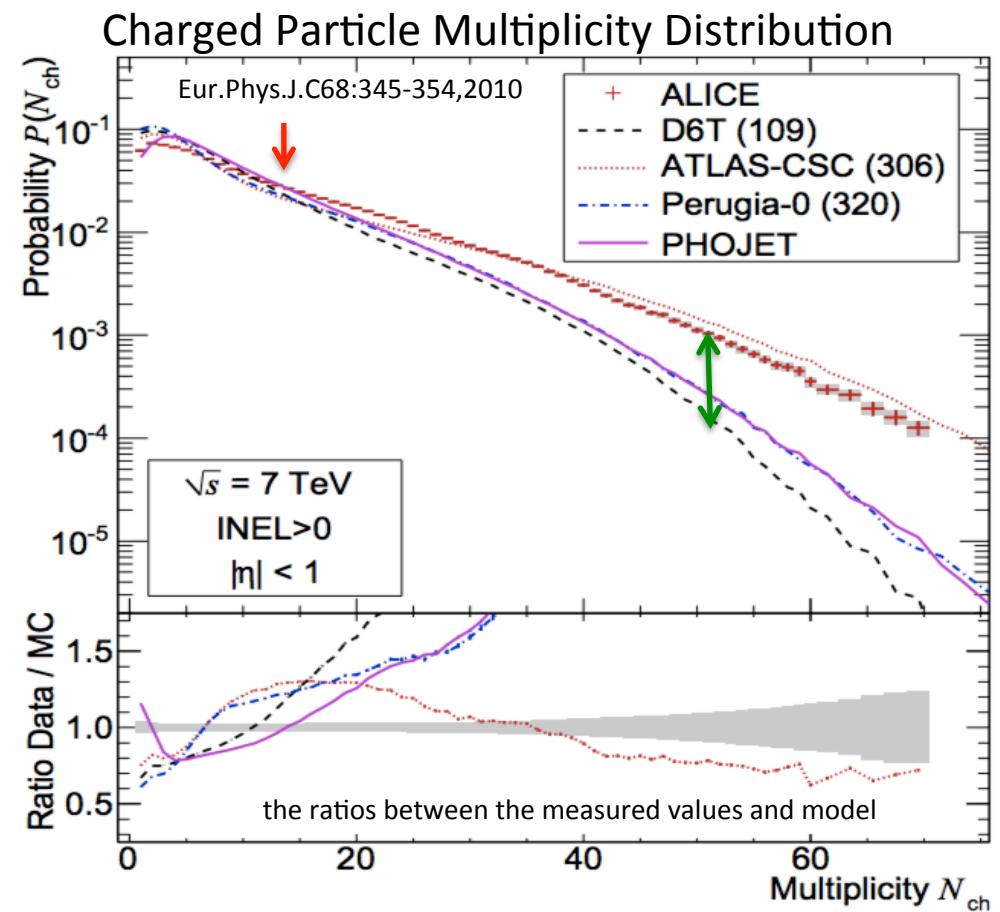
- Because of asymptotic freedom, cross section of hard process can be calculated using perturbation method.
- In hadron collisions, hard process (**superposition** of parton distribution function (PDFs), cross section).
- High multiplicity → multi-parton interaction (?)

The data at 7 TeV are compared to models:

PHOJET (solid line),  
PYTHIA tunes D6T (dashed line),  
ATLAS-CSC (dotted line) and  
Perugia-0 (dash-dotted line).

→ Pythia  
→ ATLAS-CSC is close to the data at high multiplicities ( $N_{\text{ch}} > 25$ ). However, it does not reproduce the data in the intermediate multiplicity region ( $8 < N_{\text{ch}} < 25$ ).

→ Pythia can not represent the pp collisions.



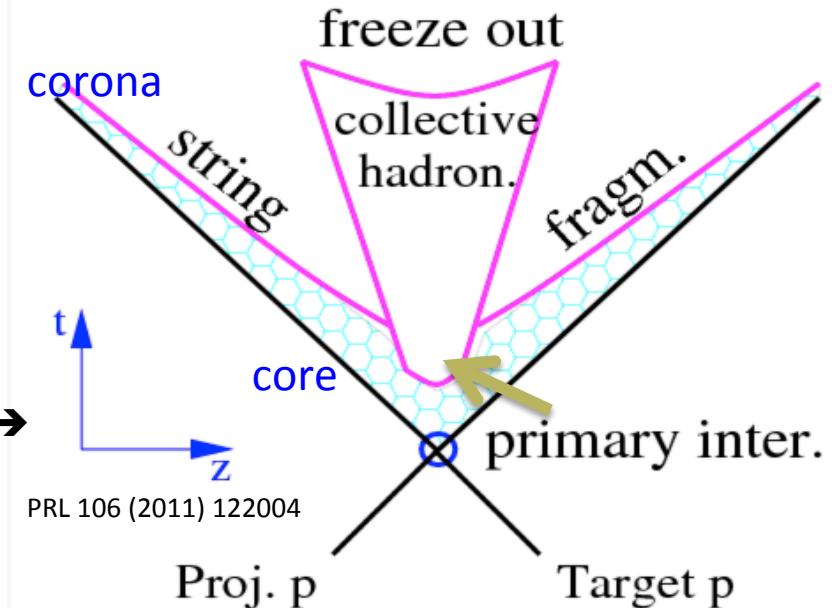
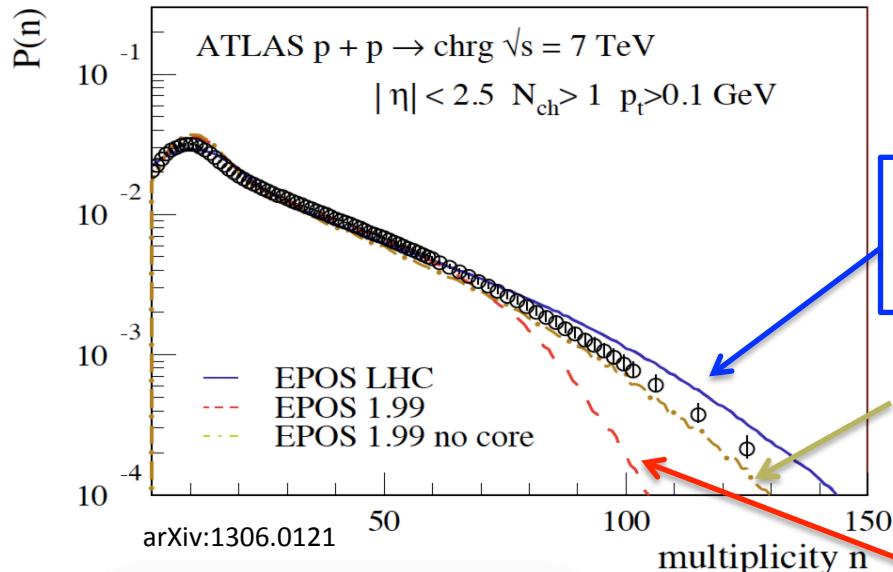
# Explanation of Collective Behavior of Parton by EPOS

- global event generator  
mean suggests both pp and heavy ion collisions are treated using the same physics.

- MC event generator for minimum bias hadronic interactions.  
-the collective hadronization in p-p scattering.

The hydrodynamic approach,  
model of EPOS 1.99 or EPOS LHC →

Multiplicity distribution of charged particles with  $p_t > 200$  MeV and  $|\eta| < 2.5$  for p-p interactions at 7 TeV from ATLAS.



PRL 106 (2011) 122004

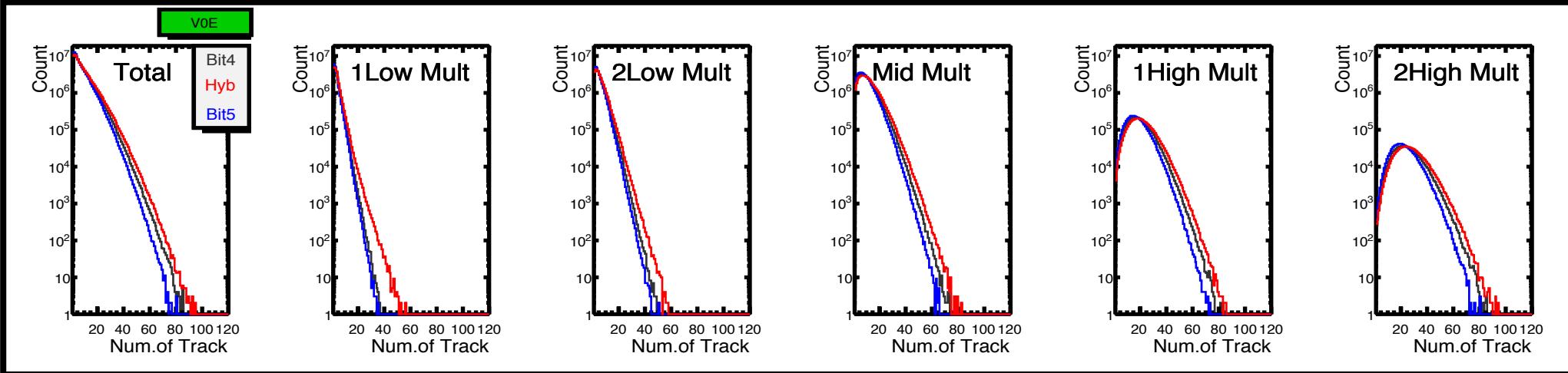
the effect of the corrected flow on the tail of the distribution  
EPOS LHC (solid line), the tail is well reproduced event with core formation.

Without core formation in EPOS 1.99 (dash-dotted line),  
the results were already reasonable.

In EPOS 1.99 (dashed line) for the events with a large multiplicity,  
the flow effect was strong and was reducing the total number of particles  
suppressing events with large multiplicities.

→ EPOS better explain pp collisions than Pythia

# Number of track and number of pair - example VOE event estimator



Hybrid track (more loose): vertex + TPC

- IsHybridGlobalConstrainedGlobal

Global track loose DCA (loose, Bit 4 ): global track cut

- kTrkGlobalNoDCA

Global track (def., Bit 5): Hybrid track + SPD track cut

- kTrkGlobal

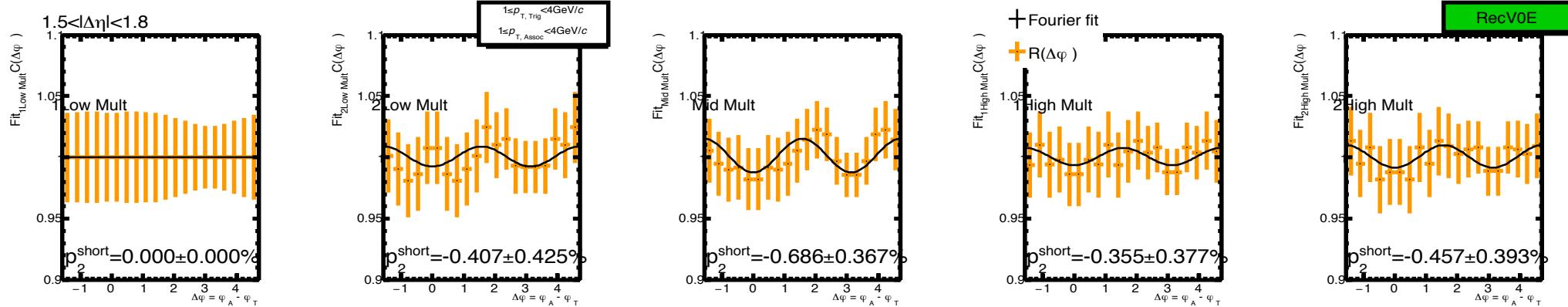
```
AliESDtrackCuts::GetStandardITSTPCTrackCuts2011(kFALSE);
- SetName("Global Hybrid tracks, loose DCA");
- SetMaxDCAToVertexXY(2.4);
- SetMaxDCAToVertexZ(3.2);
- SetDCAToVertex2D(kTRUE);
- SetMaxChi2TPCCConstrainedGlobal(36);
- SetMaxFractionSharedTPCClusters(0.4);
```

# Multiplicity dependence of the ratio $R(\Delta\varphi)$

$$= C(\Delta\varphi) / F(\Delta\varphi)$$

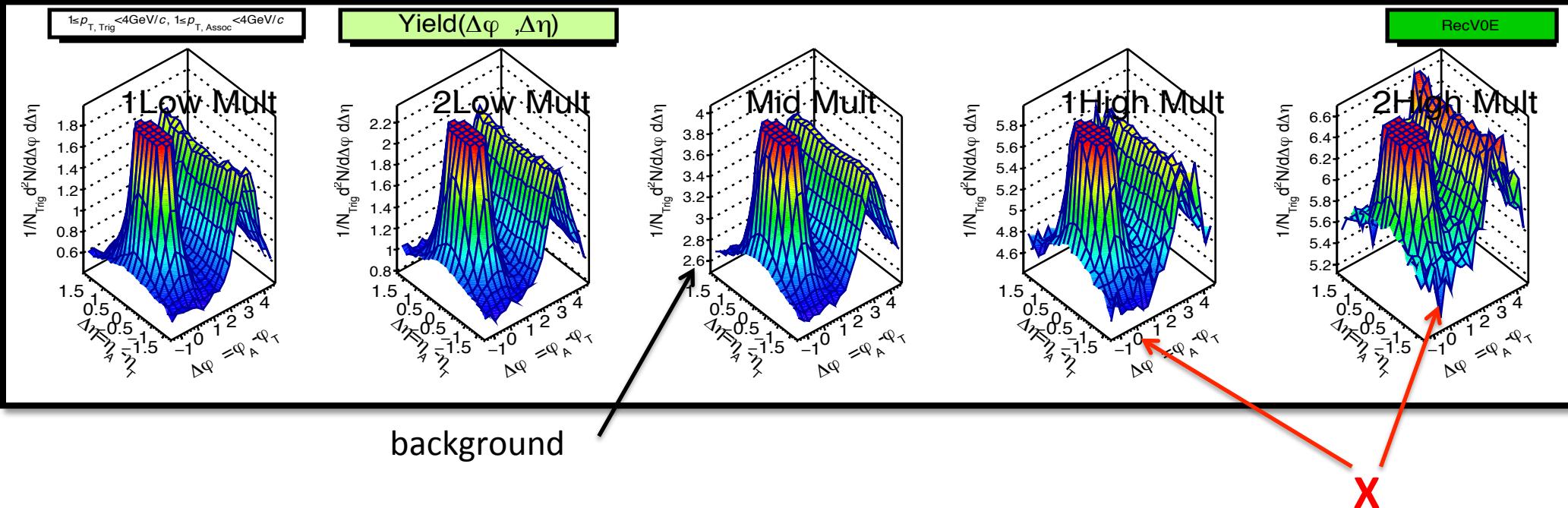
TPC-TPC correlation,  $1.5 \leq |\Delta\eta| < 1.8$

PYTHIA



# Associated particle yield per trigger

PYTHIA



Due to the combinatorial mixing back ground,  
background increase with higher multiplicity and jet size increase.

# A fitting function $F(\Delta\varphi)$ and the ratio of $C(\Delta\varphi)$ to $F(\Delta\varphi)$

Fourier:  $\frac{dN}{d\phi} \sim 1 + \cancel{2v_2 \cos 2(\phi - \psi_2)} + \cancel{2v_3 \cos 3(\phi - \psi_3)} + \dots$

Two-Particle correlation :

$$\frac{dN^{pair}}{d\Delta\phi} \sim 1 + \cancel{2v_2^2 \cos 2\Delta\phi} + \cancel{2v_3^2 \cos 3\Delta\phi} + \dots$$

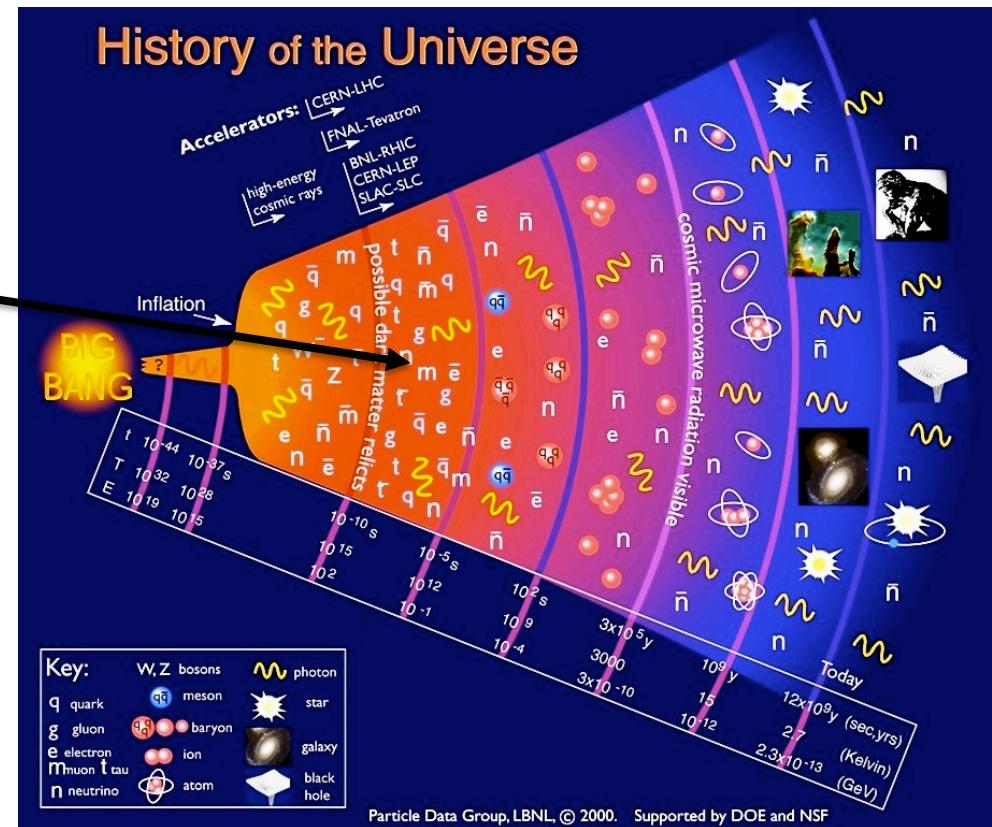
Elliptic flow      Triangular flow

$$(\varphi_2 - \Psi_2) - (\varphi_1 - \Psi_2) = \varphi_2 - \varphi_1 \\ = \Delta\varphi$$

# QGP

Quark gluon plasma  
(asymptotically free quarks and gluons)

- about  $10^{-9}$ s after big bang
- Inside of neutron star
- Heavy ion collisions experiments



collisions

thermalization

hydro

hadronization

freezeout

